An Irregular-ground Orientated Miniaturized Patch Antenna for UWB Industrial Applications

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Abstract: A new ultra small UWB antenna for different UWB industrial applications is presented here. The proposed prototype comprises of a simple structure with a modified triangular patch and a irregular ground configuration. An inexpensive FR4 substrate is used to fabricate the antenna with an overall dimension of 13×16 mm^2. To optimize antenna properties, different parts of the antenna are analyzed and presented. The antenna has 116% of impedance bandwidth from 2.8 to 10.5 GHz with VSWR<2 which covers the entire UWB. The proposed design established a nearly Omni-directional radiation characteristics over the operating frequency band with a peak gain of 5.6 dBi. The radiation efficiency is 75% on an average. The recommended antenna was successfully simulated, prototyped and measured. The uniqueness of proposed antenna is its size. The main objective of this study is to reduce the dimensions of antenna while maintaining UWB bandwidth to make it applicable for different portable and convenient UWB applications .

Keywords: UWB, Irregular-ground Orientation, VSWR, monopole antenna, Small dimension.

I. Introduction

The demand of high performance antennas with wider bandwidths is increasing exponentially due to the rapid growth of the global wireless communication industry. UWB has become a promising technology and area of interest in different industrial applications like short range communication, ranging and localization, tracking and data relay satellite(TDRSS), removable media in computers, etc. This is due to some of its striking features like high data rate, small spectral power density, high precision, low cost, robust to multi-path fading, very low interference etc. Though the Federal Communications Commission (FCC) has assigned 7.5 GHz spectrum from 3.1 to 10.6 GHz for UWB radio applications since February 2002 [1]. Typically, UWB antennas should be electronically small and inexpensive while maintaining desirable wideband performance for different industrial applications. Thus, one of the main challenges of designing UWB antennas is to get higher bandwidth, efficiency and low profile within allocated smaller dimensions.

UWB antenna characteristics can be improve by changing the shape of the radiating patch. The patch may be rectangular, circular, heart shaped, elliptical, etc. The antenna performance also can be improved by manipulating the ground structure also [2-5]. In the work of Gokmen et al. [6], a compact size UWB antenna with heart shape using triangular patches with dimensions of 25×26×0.5 mm^3, operating from 4 GHz to 19.1 GHz, is proposed. Liu and Yang [7] presented a hook-shaped UWB antenna operating from 3 GHz to 10.7 GHz with dimensions of 10 × 10 × 1.6 mm^3. In the work of Ojaroudi et al. [8], UWB monopole antenna for 3.12 to 11.2 GHz bandwidth with an inverted T-shaped notch in the ground plane is presented with a compact size of 12 × 18 mm^2. A Tapered-shaped slot antenna [9] with area of 22 × 24 mm^2 is presented with operational frequencies from 3 GHz to 11.2 GHz. In another study [10], the antenna is designed with a heart shaped patch and a defected ground plane. This antenna is proposed and optimized for ultra-wide band applications. To increase the impedance bandwidth and reduce the reflection co-efficient, three semi-circular slots were proposed in the ground plane. T. Yang and X. J. Tian[11], proposed a heart-shaped monopole patch and a couple of rectangular ground plane on the same side of a substrate. A standard impedance bandwidth is achieved from 2.1 to 11.5 GHz. Though there are some unique designs presented in literature, most of them are not compact and some of them have low fractional bandwidth.

In this letter a new and ultra small (13×16mm^2) UWB antenna with enhanced impedance bandwidth is offered. The main objective of the work is to reduce the dimensions of antenna and increase the bandwidth to make it applicable for portable and convenient UWB applications. This antenna consists of an irregular orientation ground plane bottom of back side of the substrate with rectangular shape and a patch with modified triangular shape. The inner parts of patch is partially etched away to increase the bandwidth specially for covering the lower end of the UWB frequency spectrum. With the help of triangular patch and defected ground plane, wide input impedance matching is achieved over the entire 2.9 to 10.1 GHz band with relatively stable omnidirectional radiation patterns. It has a good average peak gain. Simulated results of different frequencies for VSWR, gain, efficiency, radiation pattern, Surface Current distribution are presented along with the measured results. The simulation is performed by Computer Simulation Technology (CST) software package.

II. Antenna design and Parametric Study

A. Antenna Structure

The geometric layout of the proposed UWB antenna is depicted in Figure 1. It is printed on a FR4 substrate with dimension 13×16 mm^2 with 1.6 mm thickness. Its dielectric constant is 4.3 and loss tangent is 0.0025. The proposed antenna is composed of a partial radiating patch on one side and ground plane on opposite side of the substrate. The orientation of the ground plane and shape of patch has strong effect to the impedance matching. Therefore, by properly selecting ground orientation and patch shape, good impedance bandwidth and radiation characteristics can be reached. A triangular shape patch is developed on the front side of the antenna. In the middle of the patch a triangular pattern is etched away. This is mainly done for covering larger bandwidth specially to cover lower frequencies. A microstrip feed line of 1 mm width and 5 mm long is printed on top of the substrate. The gap from patch to end of substrate in left and right side is not same. It is much larger on th left side (G) than the right side (g), as shown in Figure 1. The ground plane of the antenna is a rectangular shape. The height of the ground plane is 4 mm and width covers the total width of antenna. The ground consist of a saw-tooth configuration on the upper side by cutting a number of triangles from a partial rectangular ground plane to improve the performance at higher frequencies. Without this irregularity, discontinuities appear in the operational bandwidth. The proposed antenna is feed by microstrip line using 50 Ω SMA connector located at the edge of the lower part of the antenna. At this point, the electromagnetic energy, which is in the form of voltage and current waves, is split into two parts. One flows along the strip line while the other continues through the edge that acts as an open transmission line. The overall size of the antenna is W×L mm^2 and the ground plane has an area of W×L_g mm^2. In Table 1 details of the optimized design parameter are summarized.

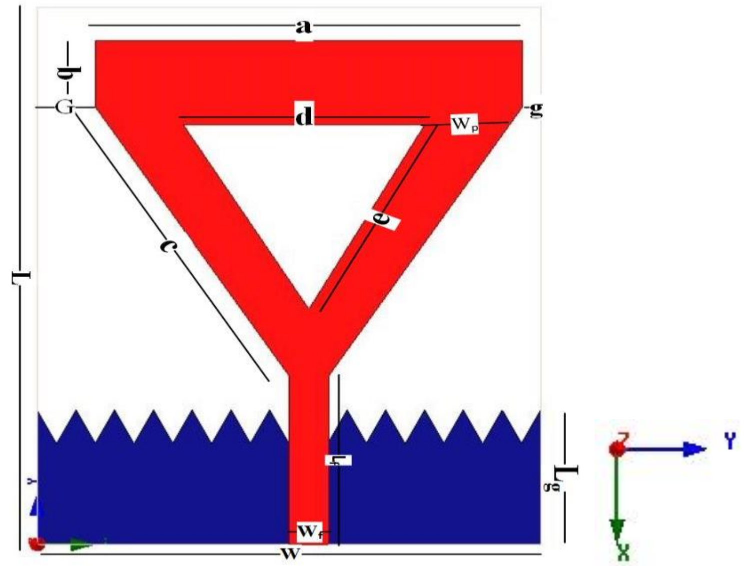


Figure 1 The geometric layout of proposed antenna (all dimension are in mm)

Table 1: Optimized Dimension of antenna prototype

Parameter	**Value (mm)**	**Parameter**	**Value (mm)**	**Parameter**	**Value (mm)**
W	13	L	16	L_g	4
W_f	1	a	11	b	2
W_p	3.1	G	1.5	g	0.5
c	9.43	d	6.25	e	6.26

The uniqueness of proposed antenna is its size. The comparison of the proposed antenna with a few recently proposed antennas [6-10] is presented in Table 2. The size of the antenna is significantly reduced in the proposed design.

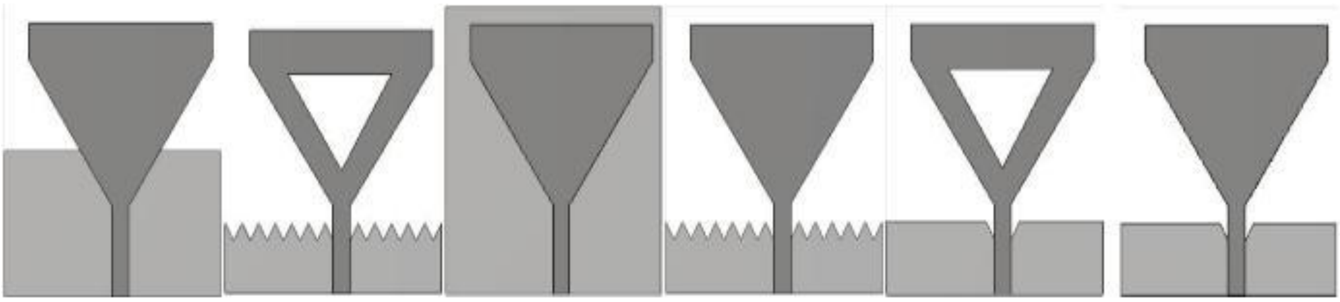
Table 2: Comparisons of proposed antenna with existing antenna

Published literature	Antenna configuration	Size Decreases (proposed/literature)
[2] Sharma and Shrivastava	Fractal elliptical	**97%**
[3] Shaalan and Ramadan	Hexagonal Monopole	**76%**
[4] Yang et al.	CPW-fed planar	**69%**
[5]Liu et al	Circular-ring	**71%**
[6] Isik and Topaloglu	Heart Shape Triangular Patch	**68%**

B. Parametric study

For investigating the effect of different parameters on antenna performance, some crucial antenna parameters were studied. At a time, single parameter is changed while others remained constant. All the parameters ware studied using 3D computational computer simulation software (CST).

1) Effect of ground and patch structure: In order to optimize the patch and ground plane, the proposed design was compared to five other structures as shown in Figure 2. Their comparative antenna performance in terms of reflection co-efficient S_{11} is shown in Figure 3. It is evident that the proposed antenna layout achieves much better performance than the other configurations. When full substrate used as ground, as shown in Figure 2(c), no reasonable operating frequency was found. When half of the substrate was used as ground, as illustrated in Figure 2(a), almost same result was recorded. In other cases like without middle triangle, without irregular orientation of ground and without both there have some band under -10dB but not contiguous. Some parts goes higher than -10 dB, hence they do not cover entire UWB bandwidth. Same parametric study for gain is depicted in Figure 4. For the gain it is seen that the proposed layout achieves better gain than other configurations.



(a) **(b)** **(c)** **(d)** **(e)** **(f)**

Figure 2: Different Geometric layout (a) with half ground plane (b) Proposed (c) Full ground (d) Without middle triangle (e) Without irregular ground orientation (f) Without both irregular ground orientation and middle triangle

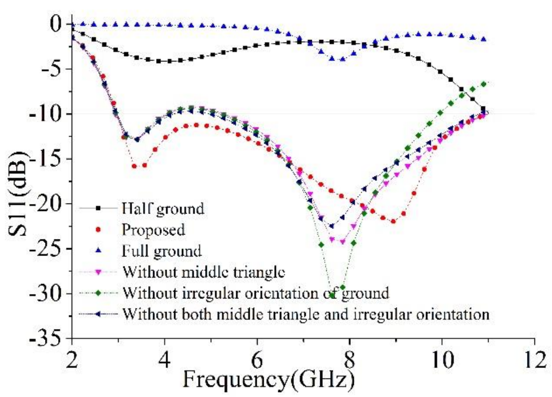


Figure 3: Simulated reflection co-efficient (S_{11}) for different structure of ground plane and patch.

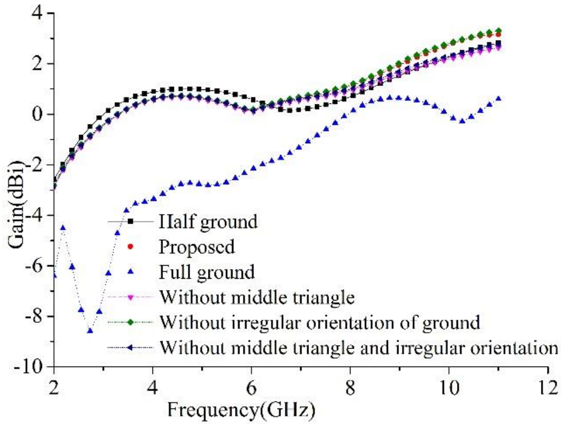


Figure 4: Simulated gain for different structure of ground plane and patch.

2) Effect of substrate material: A good selection of substrate will yield superior performance of antenna. The effect of substrate materials on impedance matching for different dielectric substrates are presented in Figure 5. The analysis would help to investigate the effects of the different substrate materials on impedance bandwidth. The chosen substrate materials are FR4 (ε_r= 4.3, tanδ = 0.025), Rogers RT 5870 (ε_r== 2.33, tanδ = 0.012), Rogers RT 6010 ($\varepsilon_{r=}$= 10.2 tanδ = 0.0023) and Glass-PTFE (ε_r== 2.33, tanδ = 0.0009). It can be clearly observed from the figure that proposed FR4 composite substrate offers wider bandwidth and lower reflection co-efficient for the proposed prototype. Due to good electrical performance, very nice dimensional stability and ideal dielectric constant, FR4 composite materials offer better performance compared to some common substrate materials.

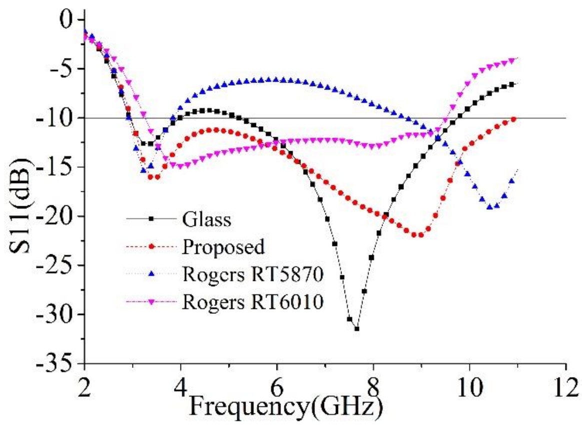


Figure 5: Simulated Reflection coefficient (S_{11}) for different substrate materials

III. Results and discussion

The photograph of the antenna prototyped for experimental verification is shown in Figure 5. For measurement, the Agilent E8362C vector network analyser (VNA) and Satimo near field anechoic chamber (UKM StarLab) is used. The simulated and experimental Voltage Standing Wave Ratio (VSWR) against frequency of the proposed antenna are illustrated in Figure 6. The measured bandwidth for VSWR ≤ 2 ranges from 2.8 GHz to 10.5 GHz and in simulation from 2.9 GHz to 10.1 GHz. In both cases it exihibits wideband performance. The measured and simulated results show a good agreement. The minor discrepancies between simulated and measured results can be attributed to imperfect fabrication and the coaxial cable used during measurement. The cable is not considered in simulation.

The size of proposed antenna is smallest among recently published antenna but it achieves a wide bandwidth. The proposed antenna cover the UWB band (3.1-10.6). A smart average gain of 4.2 dBi presented in Figure 7. The peak gain is 5.6 dBi at 8.6 GHz. In Figure 8, the simulation and measured radiation efficiencies of proposed antenna are presented. The maximaum radiation efficiency is achieved at 8.2 GHz of 89% and an average of 75% over the bandwidth.

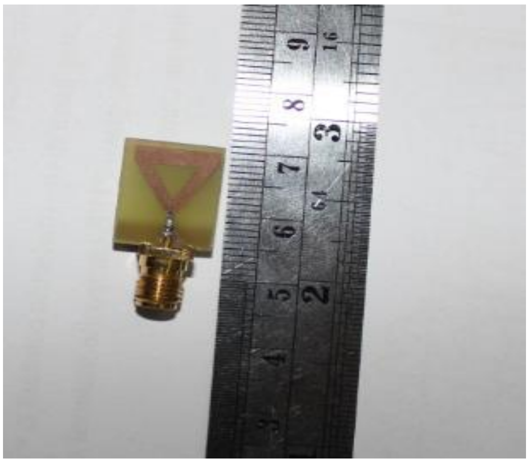


Figure 5 Photographs of the fabricated antenna: Top layer

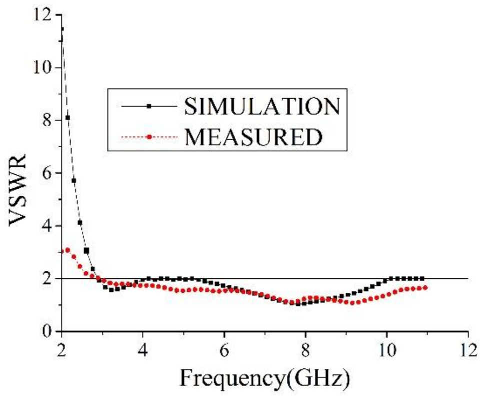


Figure 6 Simulated and Measured VSWR of the proposed antenna

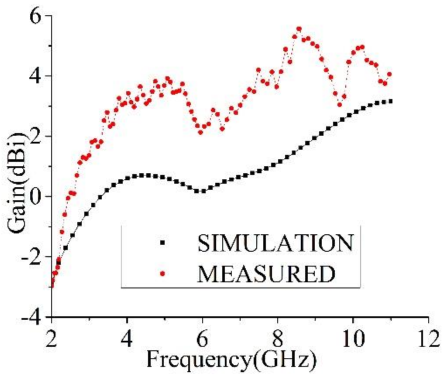


Figure 7 Simulated and Measured Gain of the proposed antenna

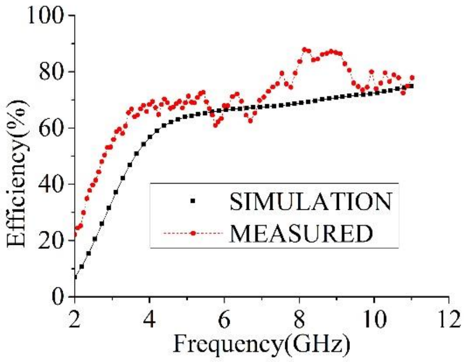
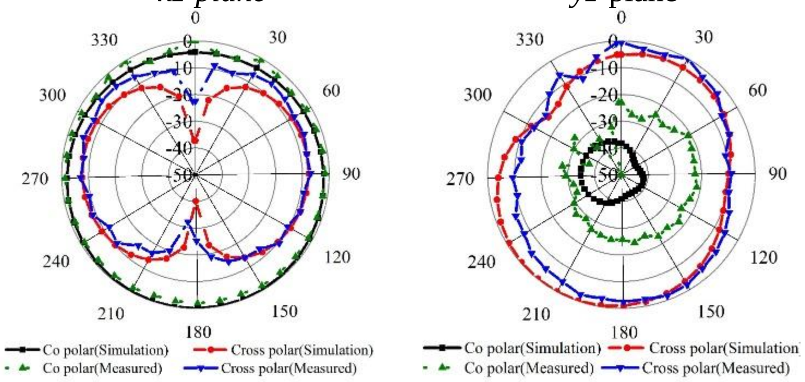


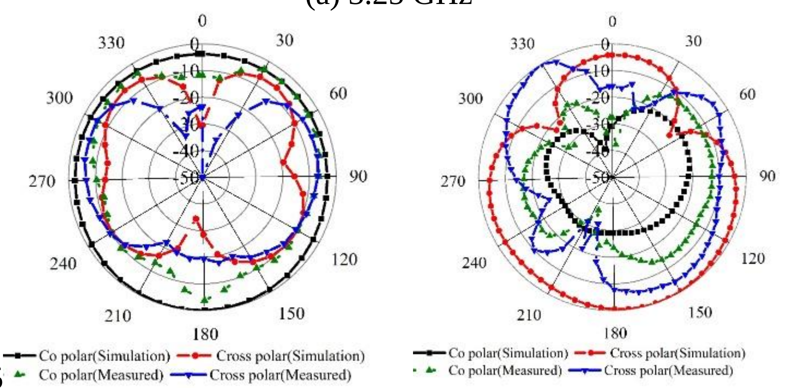
Figure 8 Simulated and Measured Efficiency of the proposed antenna

Measured radiation pattern, including the cross-polarization and co-polarization of the fabricated antenna for two resonant frequencies 3.25 GHz and 7.8 GHz in both *xz-plane(φ=0)* and *yz-plane(φ=90)*, are shown in Figure 9. It is seen that, over the desired bandwidth, the proposed antenna exhibits stable radiation pattern characteristics. At lower frequency (3.25 GHz) the radiation pattern is omnidirectional in *xz-plane*. The value of co-polarization is significantly higher than cross-polarization. With the increase of frequency to 7.8 GHz, the cross-polarization increases slightly. At peak level of the observation in Figure. 9(b) in both *xz* and *yz plane* multiple nulls can be observed in the radiation pattern as the surface currents are not distributed evenly. This indicates that the radiating element is excited with higher order modes, which typically results in more directional radiation patterns.

xz-plane *yz*-plane



(a) 3.25 GHz



(b) 7.8 GHz

Figure 9 Measured radiation pattern at different frequencies (a) 3.25 GHz (b) 7.8 GHz.

The proposed antenna and the existing antennas (literature review) were studied to ensure an impartial comparison in Table 3, where all reference antennas cover ultra-wideband spectrum. The performances parameters, such as size, applications, less than -10-dB bandwidth, dielectric constant, gain and fractional bandwidth are presented. The proposed antenna is the smallest among all the antenna studied with fair bandwidth and gain. Therefore, the proposed prototype can offer good compact characteristics for different UWB applications.

Table 3: Bandwidth, Dielectric Constant, Fractional Bandwidth and Gain comparison

Reference	Application	Size(mm^2)	BW(GHz)(VSWR<2dB)	ε	FBW(%)	Gain
[6]	UWB	25×26	4-19.1	3.5	100%	3 dBi
[7]	UWB	80×40	3-10.7	4.4	112%	4.5 dBi
[8]	UWB	12×18	3.12-12.73	4.4	120%	--------
[9]	UWB	22×24	3-11.2	4.6	115.5%	4 dBi
[10]	UWB	48×40	2.7-26	4.08	162%	<4 dBi
[11]	UWB &RFID	30×35	2.1-11.5	4.4	110%	<6dBi
Proposed prototype	UWB	13×16	2.8-10.5	4.3	116%	>4.5dBi

IV. Conclusion

The design of an irregular ground orientation antenna is extremely small size with 13×16 mm^2 monopole antenna for UWB applications. Measured results show that the antenna has an impedance bandwidth of about 116% from 2.8 to 10.5 GHz with VSWR<2 dB, a steady omnidirectional radiation pattern with 5.3 dBi peak gain and 75% of radiation efficiency over the bandwidth. The proposed design is very compact and can be used in the limited space around microwave circuitry with low manufacturing cost, which makes it ideal to integrate with portable devices. Experimental results show that the proposed antenna could be good candidate for several UWB Applications.

References

[1] F. C. Commission, "Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems,“First Report and Order,” FCC 02," *V48, April,* 2002.

[2] M. Sharma and V. Shrivastava, "Printed fractal elliptical monopole antenna for UWB application," in *Recent Advances in Microwave Theory and Applications, 2008. MICROWAVE 2008. International Conference on*, 2008, pp. 374-376.

[3] A. A. Shaalan and M. Ramadan, "Design of a Compact Hexagonal Monopole Antenna for Ultra—Wideband Applications," *Journal of Infrared, Millimeter, and Terahertz Waves,* vol. 31, pp. 958-968, 2010.

[4] Y. B. Yang, F. S. Zhang, F. Zhang, L. Zhang, and Y. C. Jiao, "A novel compact CPW-fed planar monopole antenna with modified stair-style ground for ultra-wideband applications," *Microwave and Optical Technology Letters,* vol. 52, pp. 2100-2104, 2010.

[5] L. Liu, S. Cheung, R. Azim, and M. T. Islam, "A compact circular-ring antenna for ultra-wideband applications," *Microwave and Optical Technology Letters,* vol. 53, pp. 2283-2288, 2011.

[6] G. Isik and S. Topaloglu, "A Compact Size 4–19.1 GHz Heart Shape UWB Antenna with Triangular Patches," *International Journal of Antennas and Propagation,* vol. 2013, 2013.

[7] H.-W. Liu and C.-F. Yang, "Miniature hook-shaped monopole antenna for UWB applications," *Electronics letters,* vol. 46, pp. 265-266, 2010.

[8] M. Ojaroudi, C. Ghobadi, and J. Nourinia, "Small square monopole antenna with inverted T-shaped notch in the ground plane for UWB application," *Antennas and Wireless Propagation Letters, IEEE,* vol. 8, pp. 728-731, 2009.
[9] R. Azim, M. T. Islam, and N. Misran, "Compact tapered-shape slot antenna for UWB applications," *Antennas and Wireless Propagation Letters, IEEE,* vol. 10, pp. 1190-1193, 2011.
[10] C. Figueroa Torres, J. Medina Monroy, H. Lobato Morales, R. Chavez Perez, and A. Calvillo Tellez, "Heart shaped monopole antenna with defected ground plane for UWB applications," in *Electrical Engineering, Computing Science and Automatic Control (CCE), 2014 11th International Conference on*, 2014, pp. 1-4.
[11] T. Yang and X. J. Tian, "A novel heart-shaped monopole antenna for UWB and RFID applications," *Microwave and optical technology letters,* vol. 53, pp. 2288-2291, 2011.